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THE EFFECT OF COLD ON AN INFORMATION PROCESSING TASK

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THESIS

THE EFFECT OF COLD ON AN

INFORMATION PROCESSING TASK

by

Duncan Hughes Meldrum

June 1974

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An experiment concerning the effects of cold on performance of an information processing task was designed and conducted. Performance measures were obtained under temperature conditions of 72°F, 45°F and 35°F. Performance was found to improve at the colder temperatures. An hypothesis relating arousal and cold to performance was postulated to account for the improved performance.

The Effect of Cold on an Information Processing Task

by

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ABSTRACT

An experiment concerning the effects of cold on performance of an information processing task was designed and conducted. Performance measures were obtained under temperature conditions of 72°F, 45°F and 35°F. Performance was found to improve at the colder temperatures. An hypothesis relating arousal and cold to performance was postulated to account for the improved performance.

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I. INTRODUCTION

A. BACKGROUND

The performance of mental tasks under conditions of cold stress has not been rigorously studied. Most work concerning performance in cold has involved tactual sensitivity and manual dexterity as it relates to skilled motor performance. The work presented here investigated an information processing task that did not require a high degree of skilled motor performance or tactual sensitivity in an attempt to determine if mental processes are affected by cold.

A report published by the National Aeronautics and Space Administration (1968), which summarizes existing knowledge of performance in cold, states that it is reasonable to expect performance decrements in eye-hand coordination tasks and intellectual tasks requiring fast reactions. However, it goes on to say, "So far there has been nothing reported to indicate that intellectual tasks not requiring fast reaction times, motor skills or tactual sensitivity are affected by cold exposure, at least short of the accumulation of a serious heat debt." (p. 6-125).

The effect of cold on simple reaction time was demonstrated by Teichner (1958). He used a task in which subjects responded to a visual stimulus by pressing a button located under their finger tips. No performance decrement was noted under cold conditions down to temperatures of -35° F in still air. Findikyan and Sells (1965) reported work by Torrance involving a verbal recall test. A group of men were briefed in open air at a temperature of 8° F, then allowed to rewarm. They recalled

twice as much of the contents of the briefing as a similar group that was not allowed to rewarm before recall. Horvath and Freedman (1947) administered the Johnson Code Test, which is a measure of mental performance, to a group of men living in a cold chamber at -20° F. The Code Test is a paper and pencil test, so it also measures manual dexterity as well as mental performance. Although performance was much poorer at -20° F than at room temperature, the investigators attributed the results to reduced manual dexterity rather than to any cold effects on the central nervous processes. Another attempt to determine the effects of cold on mental performance was made by Poulton (1970). He studied a vigilance task using lookouts on naval ships in Arctic and temperate regions. His task consisted of pushing a button when the lookout saw a dim light in a given sector on the horizon. Poulton found a decrement in performance under Arctic conditions.

None of the work mentioned above gives a clear indication as to whether or not mental processes are affected by cold. The objective of this work was to attempt to determine to what extent, if any, the central processes of the brain are affected by the body's exposure to cold. This entailed using a task that would measure mental performance using movements requiring a minimum motor skills and tactual sensitivity. Such a task allowed an investigation of central processes without confounding by cold effects on the physical aspects of the task performance.

B. PHYSIOLOGICAL EFFECTS OF COLD

The study of cold as a stressor is becoming increasingly important. The United States has been interested in military operations in Alaska and the Arctic since the end of World War II. The discovery of oil along

Alaska's North Shore has focused industrial attention in this area. Research and exploration in the Antarctic began, for the U. S. Navy, with Admiral Richard E. Byrd's flight over the South Pole in 1929. Construction of every station and scientific camp in the Antarctic was accomplished by U. S. Navy Seabees, including the South Pole Station in 1956-57 (Coleman, 1973; Siple, 1959). As limited resources around the world are consumed, those resources in the colder regions become more important. With interest in these colder regions becoming greater, it is important to study the limits of human performance under conditions of cold stress.

The physiological effects of cold on the body have been studied. However, the relationship between the physiological changes and any cold effects on the central nervous system is not known. A discussion of the physiological effects of cold follows in an attempt to discover if any relationship between physical changes and mental performance might be evident.

The primary defense against cold is a behavioral response to seek a more comfortable environment. Assuming this is impossible, two defenses remain. The body first attempts to control the rate of heat loss, then, if it is still unable to maintain a thermal equilibrium, active heat production begins. Once these mechanisms are employed, man has no other physiological defense against cold (Hemingway and Stuart, 1963).

The basic heat loss equation, as given by Hart (1963), is as follows:

$$H = k \frac{T_B - T_A}{I_i + I_e} . \tag{1}$$

where H = heat loss, kcal/sq. m/hr.

T_B = temperature of the body, ^oC

T_A = temperature of the air, ^oC

I_i = internal insulation in clo units

I_e = external insultaion in clo units

k = a unitless constant that is a function of the size and shape of the body.

When T_A is decreased, it is obvious that the heat loss, H, increases. By holding the external insulation constant, the only method of controlling heat loss without decreasing T_B is to increase the internal insulation. Since most body heat is transported by the blood flow and heat is given off to the environment primarily through the skin, internal insulation can be increased by reducing the blood flow to the skin. This is accomplished by vasoconstriction, or a constriction of the blood vessels. Although subcutaneous fat layers provide some tissue insulation, the primary factor in heat loss is blood flow to the periphery (Carlson and Hsieh, 1965).

Only after the limits of circulatory adjustment have been reached will the body begin to produce heat to prevent continued cooling (Carlson and Hsieh, 1965). The primary mechanism for heat production appears to be shivering, a coordinated movement of the voluntary skeletal musculature with involuntary nervous control (Hemingway and Stuart, 1963). Since the muscles are the primary heat source, exercise can also be effective in producing heat, though not as effective as shivering (Burton and Edholm, 1969). The metabolic rate is commonly used to denote heat production and has the units kcal/sq. m/hr. The important relationship between metabolic rate and temperature is demonstrated in the following equation:

$$M = \frac{55 \text{ kcal/sq. m/hr.}}{I_i + I_e} \qquad (2)$$

where M = metabolic rate, kcal/sq. m/hr.

I_i = internal insulation, clo

I_e = external insulation, clo

This equation is interpreted by Burton and Edholm (1969) in the following manner: an 18° fall in environmental temperature requires an increase in metabolic heat that is inversely proportional to the total insulation of the body. The unit of insulation commonly used is called a clo unit. The amount of insulation afforded by one clo unit is roughly equivalent to that given by a light business suit at about 68° F (Burton and Edholm, 1969).

The temperature regulating mechanism of the body is extremely complex, involving all tissues and organs with the exception of the reproductive organs. The maintenance of a thermal steady state is done by controlling the thermal conductivity of the body based on changes in the thermal gradient between the body core and skin. The cold defenses are instigated automatically, without a conscious effort. As far as the central nervous system is concerned, an increase or decrease in the temperature of the hypothalamic region of the brain will result in the necessary measures being taken to compensate for the change (Burton and Edholm, 1969, p. 100-101).

At this point, there is little evidence on which to base a theory concerning the effects of cold on mental processes. Apparently, the brain is not affected in a physical sense as long as the temperature regulating mechanisms are functioning properly, maintaining a thermal balance for the body core. A serious heat debt would obviously have an

effect, which would coincide with the onset of frostbite and hypothermia. But the effect on the central processes before the accumulation of such a heat debt is unknown. It is possible that cold would behave as one of the three stressors that have been extensively studied (heat, noise, and fatigue). Broadbent (1971) summarizes the effects on performance of these stressors in the following manner. Noise will increase the error rate after some period of time has been spent at a task. The error rate will increase immediately with heat exposure. Fatigue, in the form of sleeplessness, has no significant effect on error rate, but will slow reaction times after some time has been spent at a task.

It was felt that cold would act as a stressor and cause some decrement in performance, though the nature of the decrement was unknown. The problem was to design an experiment that would expose subjects to a cold environment. The results of the experiment would attempt to determine the nature of the influence of cold on their performance of a decision-making task.

II. THE EXPERIMENT

A. DESIGN

The objective of the experiment was to determine if cold would affect the subjects' information processing rates. The task used in the experiment was a self-paced three bit decision task. Twelve subjects were used, each acting as his own control. Control temperature was taken to be approximately room temperature (72° F). The subjects performed the task at two other temperatures, 45° F and 35° F.

A number of factors other than cold could have an effect on performance. Learning might have a significant effect no matter how well trained the subjects were. It was also felt that the order in which the subjects were exposed to the cold could be important. The design chosen to account for the three factors was a Latin Square design, as given in Kirk (1968, p. 151). If the assumption for Analysis of Variance techniques could be met, then the three factors could be tested for significance using parametric methods. Otherwise, nonparametric statistics would have to be used.

The experimental design is given in Table I. The twelve subjects were assigned randomly to three groups to meet the Latin Square requirement of an n x n array. Table I gives the order of exposure of each group to the three temperature conditions of the experiment.

TABLE I

Order of Cold Exposure

	Temperature		
	$72^{\circ}F$	$45^{\circ}F$	$35^{\circ}F$
Group I	1	2	3
Group II	3	1	2
Group III	2	3	1

B. SUBJECTS

Nine male and three female subjects participated in the experiment. All subjects were between the ages of 20 and 23 years and had spent eight months in the Monterey Peninsula area. All subjects were athletically inclined and assumed to be in good physical condition. Subjects were assigned to groups randomly, with the exception that each group was required to have one female. The analysis would attempt to determine if any significant differences in performance existed between male and female subjects. This was not expected to happen, since most differences reported between males and females in cold has been due primarily to differences in insulation (Findikyan, Duke and Sells, 1966). All subjects had equivalent insulation throughout the experiment.

In order to minimize the number of nuisance variables, all subjects were given the same instructions prior to the experiment (see Appendix A). Each subject underwent a training session consisting of 50 responses. They all wore longsleeve cotton shirts and medium weight trousers on the days of experiments. Every subject spent the same amount of time in the chamber prior to actually performing the task.

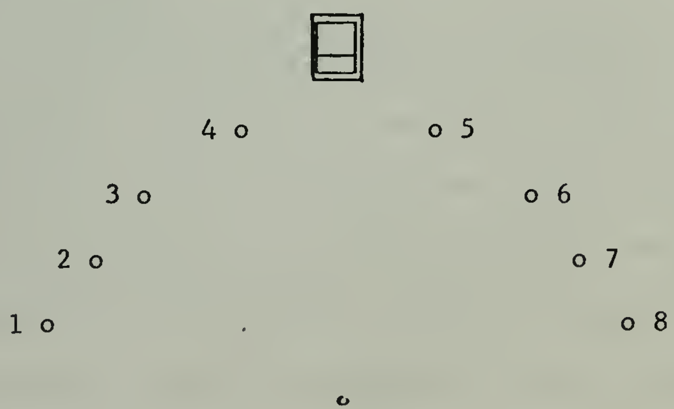
Nuisance variables that were uncontrollable by the experimenter consisted mainly of the physical characteristics of the subjects (height, weight, heart rate and oral temperature). Although subjects took the tests at times ranging from 0900 to 1800 during the day, a subject always performed the task at the same time each day. As has been mentioned, the order of exposure to the temperatures was a controlled variable. The training session was given prior to the first day of testing. Subjects were tested on three successive days at the temperatures required for their groups.

C. TASK AND EQUIPMENT

A self-paced button pushing task was used to obtain a measure of choice reaction time. The response panel (Figure 1) consisted of a semicircular array with a zero button at the center. Eight response buttons were numbered one through eight from left to right, respectively. The distance from the zero button to each response button was eleven inches. The buttons were all one inch in diameter.

Figure 1

Response Panel



The stimulus was presented by a seven segment digital screen centrally located at the top of the response panel. A zero was normally displayed on the screen. A subject would instigate a response cycle by pressing and releasing the zero button. Upon release, a pulse was sent to a tape reader and the Lab 8/e Digital computer. The computer started timing the response as the tape reader simultaneously presented the stimulus. The stimulus was a number from one to eight. Each number had an equal probability of appearing on the screen. They were presented in a random manner. The total uncertainty at each response was $\log_2(8)$ or 3 bits. Once the stimulus appeared, the subject had to press the response button corresponding to the number of the stimulus. As soon as a response button was pressed, whether it was the correct one or not, the computer stopped timing the response and the tape reader stepped once, replacing the stimulus number with a zero. Incorrect responses were recorded on a brush recorder.

The basic assumption to this task was that movement time would be constant under each temperature condition. This is a reasonable assumption since the task did not require a high level of motor skill or manual dexterity. The only variable portion of the choice reaction time would be the time it took for the subject to recognize the stimulus and initiate his response.

The response panel was located in a sound proof chamber that was temperature controlled. Subjects were required to spend twenty-five minutes in the chamber prior to doing the task. The training session, given a day before the first test, consisted of fifty responses. The actual test consisted of 100 responses. Subjects' heart rates and oral temperatures were taken prior to entering the chamber, just before the task began and immediately following task completion.

At the end of each run, subjects were informed of their average response times and the number of errors they had committed. Any questions concerning the outcome of the experiment were given a non-commital answer. In this way, subjects performance would not be affected by pre-conceived notions as to what the outcome would be.

D. PERFORMANCE MEASURE

Subject performance was characterized by two components, an average response time and an error total. The average response time was taken over the middle eighty-one responses. The first nine responses were discarded to allow for a warm-up period. Although the subjects did not know how many responses they had made at any given point, it was felt that they might anticipate the end of the task. Any confounding by the anticipation was hopefully reduced by discarding the last ten responses.

In order to combine the errors and the average response time into one performance measure, it was decided to weight the response time by an error factor. This was accomplished by multiplying the average response time by the ratio of the total responses to the number of correct responses. This procedure presumes that an error was caused by a too hasty decision and that an error would not have occurred if the subject had taken more time in responding. The average response time is increased as a function of errors.

Let N be the total number of responses and let N_c be the total number of correct responses. If t_i is the response time of the i^{th} response, then the average response time, $\bar{t}$ is found by

$$\bar{t} = \frac{1}{N} \sum_{i=1}^{N} t_i \ . \qquad (3)$$

The performance measure, T, was determined from the following expression:

$$T = \frac{1}{N} \sum_{i=1}^{N} t_i \left(\frac{N}{N_c}\right) = \bar{t} \left(\frac{N}{N_c}\right) . \qquad (4)$$

The variance of the unweighted response times is given by

$$\mathrm{Var} = \frac{1}{N} \sum_{i=1}^{N} (t_i - \bar{t})^2 . \qquad (5)$$

Equation (5) was modified by multiplying the response times and average response times by the weighting factor, N/N_c to obtain the weighted variance.

$$\mathrm{Var}_T = \frac{1}{N} \sum_{i=1}^{N} \left(t_i \frac{N}{N_c} - \bar{t} \frac{N}{N_c}\right)^2 = \left(\frac{N}{N_c}\right)^2 \mathrm{Var}. \qquad (6)$$

Table II, the data summary, gives the performance measure and variance as determined by equations (4) and (6) for each run of the task.

TABLE II

Data Summary

Group		72°F		45°F		35°F	
		Performance Measure	Variance	Performance Measure	Variance	Performance Measure	Variance
I	S1	0.809	0.0123	0.848	0.0260	0.852	0.0305
	S2	0.776	0.0163	0.783	0.0098	0.774	0.0135
	S3	0.845	0.0120	0.838	0.0120	0.809	0.0091
	S4*	0.913	0.0074	0.867	0.0061	0.859	0.0059
II	S5*	0.906	0.0159	1.001	0.0257	0.897	0.0129
	S6	0.954	0.0165	0.981	0.0156	0.921	0.0103
	S7	0.800	0.0088	0.923	0.0155	0.819	0.0151
	S8	0.845	0.0139	0.877	0.0067	0.839	0.0083
III	S9	0.867	0.0177	0.860	0.0050	0.896	0.0111
	S10	0.905	0.0513	0.911	0.0304	0.920	0.0251
	S11	0.937	0.0581	0.855	0.0199	0.883	0.0180
	S12*	0.777	0.0187	0.734	0.0175	0.759	0.0122

*Female Subject

III. DATA ANALYSIS

A. PARAMETRIC ANALYSIS

The basic assumption of Analysis of Variance techniques is that the performance measures be randomly selected from a normally distributed population. As long as there are no gross departures from normality, the robustness of the F test will allow for accurate results. No apparent departures from normality were evident in the data. The second assumption of ANOV techniques is that the variances of the scores be equal. The statistic F_{max} was used to test this hypothesis for each of the nine blocks of the Latin Square design. The null hypothesis of equal variance was rejected in seven of the nine blocks (see Appendix B.1). Even though the assumption of homogenity of variances was not met, Kirk (1968) states that the F distribution is robust with respect to the violation of this assumption. Thus, a parametric analysis was done on the data.

The results of the Latin Square analysis (Table III) indicate that the only factor that had a significant effect on performance was the group to which a subject belonged. This counter-intuitive result suggested that the violation of the variance homogenity assumption was important. Non-parametric methods were resorted to in an attempt to substantiate or clarify the results of the parametric analysis.

TABLE III

Analysis of Variance

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F
Group	2	0.027	0.0135	3.792*
Temperature	2	0.003	0.0015	0.42
Learning	2	0.008	0.004	1.123
Residual	2	0.005	0.0025	0.702
Within Cell	27	0.096	0.00356	

* $\alpha = 0.05$

B. NONPARAMETRIC ANALYSIS

The Wald-Wolfowitz runs test was used to test the hypothesis that the scores by the females were not different than the scores of the male subjects. If there are any differences in the samples, then the null hypothesis that the samples were from the same population is rejected. This test was done on the scores for the subjects under the three temperature conditions (Appendix B.8). The null hypothesis was accepted under all three conditions. Therefore, the performance times of the female subjects could be analyzed in conjunction with the male performance times.

The Friedman two-way analysis of variance was used to test the hypothesis that cold had no effect on performance. Since rejection is more powerful than acceptance for this test, a rejection of the null hypothesis would be a definite indication that cold affected the response times of the subjects. However, the null hypothesis was accepted (Appendix B.2).

Since it was possible that learning confounded the results above, a Friedman two-way analysis of variance was carried out to determine if the day of the test was important (Appendix B.3). The null hypothesis that the day of testing was not significant was rejected at an $\alpha = 0.05$ level. Eight of the twelve subjects had their slowest response times on the first day of testing, while only one had his fastest time on the first day. This led to the conclusion that learning was an important factor in the first day's performance. A Wilcoxon matched-pairs signed-ranks test was carried out to determine if learning had a significant effect on performance on the second or third days (Appendix B.4). The result of this test showed that learning did not significantly affect performance after the first day of testing.

The response times recorded by the subject on the first day were disregarded from further analysis in an attempt to determine cold's effect on performance. Subjects' performances were categorized by "warmer" and "colder". Nine subjects produced faster times in colder conditions. A Wilcoxon test was used to test the hypothesis that no significant difference existed between performance under the two conditions. This was rejected at a 0.025 level of significance (Appendix B.5). Performance under colder conditions increased for an information processing task.

Further nonparametric analysis was made to determine if there was any correlation between the nuisance variables of body surface area, as determined by height and weight, and the time of day the test was administered (Appendix B.6, B.7). A Spearman rank test determined that no correlation between body surface area and the performance was significant. There was also no significant correlation between time of test and performance.

IV. DISCUSSION OF RESULTS

Normally, one would expect a stressor such as cold to have an adverse effect on performance. However, once the effect of learning had been removed from the data, only three of twelve subjects showed a performance decrement in the experiment. Two hypotheses are suggested as possible explanations for this result.

The first and rather simple hypothesis is that the subjects hurried their responses, either consciously or subconsciously, to shorten the time spent in the chamber, thereby masking the influence of cold. They knew that once the task was completed and their heart rate and temperature were taken, they would be leaving the cold chamber. If this knowledge did affect them, one would expect the errors to increase as subjects rushed their responses. However, no significant increase in errors occurred under the two cold conditions. It was also felt that since the subjects did not have knowledge of the exact length of the task, it was not very probable that this was a valid hypothesis.

A more reasonable hypothesis is one which involves the task difficulty and the effect of cold on the body. Welford (1973) states that a man functions best under conditions of moderate demand. If demand is too low, a person will be under-aroused. The low arousal state will be evident in a lack of alertness, drowsiness, or extreme muscle relaxation (Duffy, 1962). If one is performing in an under-aroused state, errors of omission rather than commission are most likely to occur. However, in a self-paced task such as the one used in this experiment, it is impossible for omission errors to occur. One would expect slower response

times, then, if subjects were under-aroused. Since the task used here was not complex, it is quite possible that the subjects performed in a state of low arousal at the room temperature conditions.

The addition of cold to the environment could have increased the level of arousal of the subjects more than enough to compensate for the stress. The autonomic responses of the body to cold are similar to the conditions noted when the arousal level of an individual increases. Eason, et. al. (1965) noted increased muscle tension, decreased skin conductance, and no change in heart rate when activation, or arousal, increased. The increase in muscle tension occurred when the subjects had spent time in the cold as part of the physiological response to cold. No change in heart rate occurred when the subjects were in the cold chamber. Activation of the brain, which accompanies arousal, appears to be correlated with autonomic responses (Welford, 1973). This activation depolarizes the cells of the cortex, which makes the cells more susceptible to firing by an incoming stimulus. Therefore, it is possible that the organismic response to the cold could lead to an increased level of arousal. The increase may enhance a subject's ability to recognize and process a signal more quickly than he did at room temperature.

Duffy (1962) states that complex tasks are disrupted by higher activation while easy tasks are aided by it. She defines task complexity in terms of the number or cues which must be utilized simultaneously to achieve success. In terms of that definition, the decision processing task used here is not complex. One would therefore expect performance to improve when the level of arousal increased as a result of the cold exposure. A more complex task, with its initial higher level of arousal at room temperature, would probably be performed more poorly in colder temperatures.

V. CONCLUSIONS AND RECOMMENDATIONS

An increase in performance occurred under conditions of cold. This increase became apparent after the confounding effects of learning had been removed from the data. The order of exposure to the different temperature conditions was unimportant. There was no correlation between body surface area, as determined by height and weight, and task performance. There was also no significant correlation between performance and the time of day a subject did the task.

Since the lowest temperature considered in the experiment was 35° F, it is recommended that further research be done to determine the lower temperature bound for increased performance in a decision task. Such work should also include an investigation of the cold-arousal hypothesis presented in the last section. This would entail observations of physiological responses as well as performance measures.

Performance of a task that has various information load levels should also be investigated to determine if overloading occurs with lesser or greater information processing rates in lower temperatures. If the maximum performance level increases or decreases for a subject under cold conditions, a work load should be adjusted to compensate for the difference. Although an increased performance was noted for a three-bit decision task, a more complex task might not be accomplished as easily under cold conditions as it was at room temperature.

APPENDIX A

Subject Instruction

1. Wear

    1. Long sleeve cotton shirts--open at collar.

    2. Medium weight trousers.

II. Task Performance

    1. Use index finger of preferred hand to push buttons.

    2. Press zero button and hold until ready for stimulus.

    3. Release zero button. A number will appear on the screen. Press the numbered button corresponding to the number on the screen. This is the time I am measuring.

    4. When the numbered button has been pressed, a zero will return to the screen. Press the zero button and continue the process as in step (2).

    5. I will inform you when 100 trials have been completed. Please wait in the chamber for me to take your temperature and heart rate.

    6. If you make a mistake, continue the process as if you had not made any. Errors are recorded automatically by the equipment.

    7. If you have any questions, please ask them; either now or over the intercom. If for some reason you wish to ask a question during the test, do so when a zero shows on the screen.

APPENDIX B.1

Test for Equal Variances

H_0: The variances are all equal.

H_1: There is a significant difference between the variances.

Criterion: If $F_{max} = \dfrac{\sigma_j^2 \text{ largest}}{\sigma_j^2 \text{ smallest}}$ is greater than F_α, reject H_0.

F_{max} for each block:

	Temperature		
	72°	45°	35°
Group I	2.20*	4.26**	5.17**
Group II	1.88	3.84**	1.82
Group III	3.28**	6.08**	2.26*

* significant at $\alpha = 0.05$

** significant at $\alpha = 0.01$

Since F_{max} is greater than $F_{\alpha = 0.05}$ in seven out of nine blocks, H_0 must be rejected. A significant difference exists among variances within each cell.

APPENDIX B.2

Friedman Two-Way Test for Cold Significance

H_0: Cold has no effect, i.e. the mean ranks of the columns are equal.

H_1: Cold has a significant effect on performance.

Rank of Fastest to Slowest (1 to 3)
Response Times for Each Subject

	Temperature		
	72°F	45°F	35°F
S1	1	2	3
S2	2	3	1
S3	3	2	1
S4	3	2	1
S5	2	3	1
S6	2	3	1
S7	1	3	2
S8	2	3	1
S9	2	1	3
S10	1	2	3
S11	3	1	2
S12	3	1	2
R_j	25	26	21

(k-1) = 2 degrees of freedom

$$\chi_r^2 = \frac{12}{12(3)\ (4)} \left[25^2 + 26^2 + 21^2\right] - (3)\ (12)\ (4) = 1.17$$

The probability of obtaining $\chi_r^2 = 1.17$, with n = 12 and 2 degrees of freedom, is between 0.5 and 0.7. Therefore, the null hypothesis cannot be rejected.

APPENDIX B.3

Friedman Two-Way Test for Test Day Significance

H_0: The day of testing is not important.

H_1: The response times were dependent on the day of testing.

Rank of Fastest to Slowest Response Times
Based on Day of Testing

	Day		
	1st	2nd	3rd
S1	1	2	3
S2	2	3	1
S3	3	2	1
S4	3	2	1
S5	3	1	2
S6	3	1	2
S7	3	2	1
S8	3	1	2
S9	3	2	1
S10	3	1	2
S11	2	3	1
S12	2	3	1
R_j	31	23	18

$\chi_r^2 = 7.17$ $\qquad$ k-1 = 2 degrees of freedom

The probability of $\chi_r^2 = 7.17$ for n = 12 and 2 degrees of freedom is between 0.05 and 0.02. Therefore, H_0 can be rejected at an $\alpha = 0.05$ level of significance. A subject's performance did depend on the day he was tested.

APPENDIX B.4

Wilcoxon Test for Learning Effects

H_0: Learning did not have a significant effect on performance between the second and third day of testing.

H_1: Learning had a significant effect on performance.

Response Times of Second and Third Day of Testing

	Day 2nd	3rd	d	Rank of d	Rank with Less Frequent Sign
S1	.848	.852	.004	1	1
S2	.783	.774	-.009	-6.5	
S3	.838	.809	-.027	-9	
S4	.867	.859	-.008	-5	
S5	.897	.906	.009	6.5	6.5
S6	.921	.954	.033	10	10
S7	.819	.800	-.019	-8	
S8	.839	.845	.006	2.5	2.5
S9	.867	.860	-.007	-4	
S10	.905	.911	.006	2.5	2.5
S11	.937	.855	-.082	-12	
S12	.777	.734	-.043	-11	
					T = 22.5

$T_{\alpha=0.05} = 14$ Since $T < T_{\alpha=0.05}$, accept H_0; learning does not have a significant effect on performance between the second and third days of testing.

APPENDIX B.5

Wilcoxon Test for Cold Effects between Second and Third Day

H_0: Performance in warmer conditions does not differ from performance in colder conditions.

H_1: Performance is slower in warmer temperature.

Response Times of Subjects' Second and Third Test Days
Arranged According to Warmer and Colder Temperatures

	Warmer	Colder	d	Rank of d	Rank with Less Frequent Sign
S1	.848	.852	.004	1	1
S2	.783	.774	-.009	-6.5	
S3	.838	.809	-.027	-9	
S4	.867	.859	-.008	-5	
S5	.906	.897	-.009	-6.5	
S6	.954	.921	-.033	-10	
S7	.800	.819	.019	8	8
S8	.845	.839	-.006	-2.5	
S9	.867	.860	-.007	-4	
S10	.905	.911	.006	2.5	2.5
S11	.937	.855	-.082	-12	
S12	.777	.734	-.043	-11	
					T = 11.5

Since $T_{\alpha=0.025} = 14$ is greater than $T = 11.5$, reject H_0. Performance is slower under warmer temperature conditions.

APPENDIX B.6

Spearman Rank Test for Significant Correlation Between Body Surface Area and Performance

H_0: There is no significant correlation between body surface area (BSA) and performance.

H_1: The correlation between BSA and performance is significant.

$72^{\circ}F$

	Response Time	Rank	BSA (m^2)	Rank	$(d_i)^2$
S1	.809	4	1.81	5.5	2.25
S2	.776	1	1.85	7	36
S3	.845	5.5	1.96	9	12.25
S4	.913	10	1.60	3	49
S5	.906	9	1.56	2	49
S6	.954	12	1.94	8	16
S7	.800	3	2.04	11	64
S8	.845	5.5	1.81	5.5	0
S9	.867	7	2.00	10	9
S10	.905	8	1.79	4	16
S11	.937	11	1.84	6	25
S12	.777	2	1.52	1	1

$$\sum (d_i)^2 = 279.5$$

$$r_s = 1 - \frac{6(279.5)}{1728} = 0.03$$

This value of r_s is not significant for $n = 12$. Therefore, H_0 must be accepted.

$45^{\circ}F$

	Response Time	Rank	BSA Rank	$(d_i)^2$
S1	.848	4	5.5	2.25
S2	.783	2	7	25
S3	.838	3	9	36
S4	.867	7	3	16
S5	1.001	12	2	100
S6	.981	11	8	9
S7	.923	10	11	1
S8	.877	8	5.5	6.25
S9	.860	6	10	16
S10	.911	9	4	25
S11	.855	5	6	1
S12	.734	1	1	0

$$\sum (d_i)^2 = 237.5$$

$$r_s = 1 - \frac{6(237.5)}{1728} = 0.175$$

This value of r_s is not significant for n = 12. Therefore, H_0 must be accepted.

$35^{\circ}F$

	Response Time	Rank	BSA Rank	$(d_i)^2$
S1	.852	6	5.5	.25
S2	.774	2	7	25
S3	.809	3	9	36
S4	.859	7	3	16
S5	.897	10	2	64
S6	.921	12	8	16
S7	.819	4	11	49
S8	.839	5	5.5	.25
S9	.896	9	10	1
S10	.920	11	4	49
S11	.883	8	6	4
S12	.754	1	1	0

$$\sum (d_i)^2 = 260.5$$

$$r_s = 1 - \frac{6(260.5)}{1728} = 0.095$$

This value of r_s is not significant for n = 12. The null hypothesis must again be accepted.

APPENDIX B.7

Spearman Rank Test for Significant Correlation Between Time of Test and Performance

H_0: There is no significant correlation between the time of day a subject took the test and his performance.

H_1: The time of day was significantly correlated with performance.

	Time Took Test	Rank	Response Times Rank 72°	45°	35°	$(d_i)^2$ 72°	45°	35°
S1	1000	4	4	4	6	0	0	4
S2	1300	7	1	2	2	36	25	25
S3	1600	11	5.5	3	3	30.25	64	64
S4	1620	10	10	7	7	0	9	9
S5	1520	9	9	12	10	0	9	1
S6	1020	5	12	11	12	49	36	49
S7	0920	2	3	10	4	1	64	4
S8	0900	1	5.5	8	5	20.25	49	16
S9	0940	3	7	6	9	16	9	36
S10	1345	8	8	9	11	0	1	9
S11	1700	12	11	5	8	1	49	16
S12	1240	6	2	1	1	16	25	25
					$\sum(d_i)^2$ =	169.5	340	258

$$72^\circ: \quad r_s = 1 - \frac{6(169.5)}{1728} = 0.411, \text{ not significant}$$

$$45^\circ: \quad r_s = 1 - \frac{6(340)}{1728} = -0.181, \text{ not significant}$$

$$35^\circ: \quad r_s = 1 - \frac{6(258)}{1728} = 0.104, \text{ not significant}$$

Since none of the correlation coefficients are significant, H_0 can be accepted for all three temperature conditions. There is no significant relationship between performance and the time a subject took the test.

APPENDIX B.8

Wald-Wolfowitz Runs Test for Subject Similarity

H_0: The scores of the female subjects and male subjects were drawn from the same population.

H_1: The scores of the female subjects were drawn from a population that differed from the population of male subjects' scores.

72^o

Female Scores	.777	.906	.913						
Male Scores	.776	.800	.809	.845	.845	.867	.905	.937	.954

Ranking (lowest to highest) M F MMMMMM FF MM
Runs (r) 1 2 3 4 5

since $r = 5 > r_{\alpha=0.05} = 3$, accept H_0

45^o

Female Scores	.734	.867	1.001						
Male Scores	.783	.838	.848	.855	.860	.877	.911	.923	.981

Ranking F MMMMM F MMMM F
r 1 2 3 4 5

since $r = 5 > r_{\alpha=0.05} = 3$, accept H_0

35^o

Female Scores	.759	.859	.897						
Male Scores	.774	.809	.819	.839	.852	.883	.896	.920	.921

Ranking F MMMMM F MM F MM
r 1 2 3 4 5 6

since $r = 6 > r_{\alpha=0.05} = 3$, accept H_0

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